STRAIN MEASUREMENT

Prepared by..
Prof.Sachin Kumar Nikam

DEPARTMENT OF MECHANICAL ENGINEERING

CONTENT

- STRAIN GAUGES DEFINITION
- TYPES OF STARIN GAUGES
- GAUGE FACTOR DERIVATION

CONTINUE

STRAIN GAUGES

A **Strain gauge** (sometimes referred to as a Strain gage) is a sensor whose resistance varies with applied force; Strain Gauge or Strain Gage was invented in 1938 by Edward E. Simmons and Arthur C. Ruge.

It is one of the significant sensors used in the geotechnical field to measure the amount of strain on any structure (Dams, Buildings, Nuclear Plants, Tunnels, etc.). The resistance of a strain gauge varies with applied force and, it converts parameters such as force, pressure, tension, weight, etc. into a change in resistance that can be measured later on.
Whenever an external force is applied to an object, it tends to change its shape and size thereby, altering its resistance. The stress is the internal resisting capacity of an object while a strain is the amount of deformation experienced by it.
We know, resistance is directly dependent on the length and the cross-sectional area of the conductor given by:

$$R= \rho L/A$$

Where,
R = Resistance
L = Length
A = Cross-Sectional Area
P = Resistivity of the material

CHARACTERISTICS OF STRAIN GAUGES:

The characteristics of strain gauges are as follows:

1. They are highly precise and don’t get influenced due to temperature changes. However, if they do get affected by temperature changes, a thermistor is available for temperature corrections.

2. They are ideal for long distance communication as the output is an electrical signal.

3. Strain Gauges require easy maintenance and have a long operating life.

4. The production of strain gauges is easy because of the simple operating principle and a small number of components.

5. The strain gauges are suitable for long-term installation. However, they require certain precautions while installing.

6. All the strain gauges produced by Encardio-Rite are hermetically sealed and made up of stainless steel thus, waterproof.

7. They are fully encapsulated for protection against handling and installation damage.

8. The remote digital readout for strain gauges is also possible.

TYPES OF STRAIN GAUGES

Strain gauges are basically available into four types of:

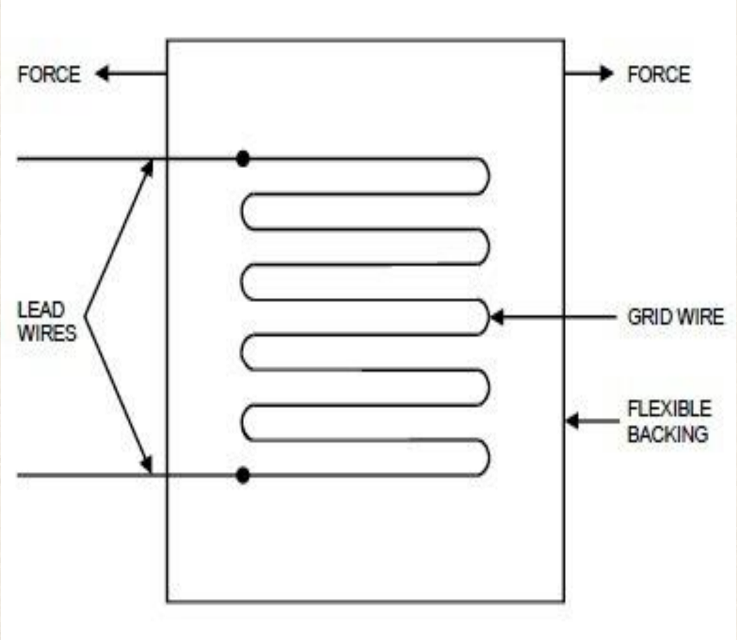
1. Wire wounded strain gauges
2. Foil type strain gauge
3. Semiconductor strain gauges
4. Capacitive strain gauges

1. **Wire wounded strain gauges:** In an electrical resistance strain gauge, the device consists of a thin wire placed on a flexible paper tissue and is attached to a variety of materials to measure the strain of the material. This change in resistance is proportional to the strain and is measured using a Wheatstone bridge.

There are two main classes of wire wound strain gauges:

- Bonded strain gauge
- Unbonded strain gauge

Bonded strain gauge: These gauges are directly bonded (that is pasted) on the surface of the structure under study. Hence they are termed as bonded strain gauges. Along with the construction of transducers, a bonded metal wire strain gauge is used for stress analysis. A resistance wire strain gauge has a wire of diameter 0.25mm or less.



The grid of fine resistance wire is cemented to carrier. It can be a thin sheet of paper, Bakelite or a sheet of Teflon. To prevent the wire from any mechanical damage, it is covered on top with a thin sheet of material. The spreading of wire allows us to have a uniform distribution of stress over the grid. The carrier is bonded with an adhesive material. Due to this, a good transfer of strain from carrier to a grid of wires is achieved.

A resistance wire strain gauge must possess the following characteristics in order to have desirable results-

1. The strain gauge should have a high value of gauge factor. As high gauge factor indicates a large change in resistance, which leads to high sensitivity.

2. The gauge resistance should be high so as to minimize the effect of undesirable variations of resistance in measurement circuits.

Typically, the resistance of strain gauges is 120Ω, 350Ω, 1000Ω. But a high resistance value results in lower sensitivity. Thus to have higher sensitivity, higher bridge voltages have to be used.

- The strain gauge should have low resistance temperature coefficient.

- It should possess linear characteristics in order to have the constancy of calibration over its entire range.

- Strain gauges must have a good frequency response. The linearity should be maintained within accuracy limits.

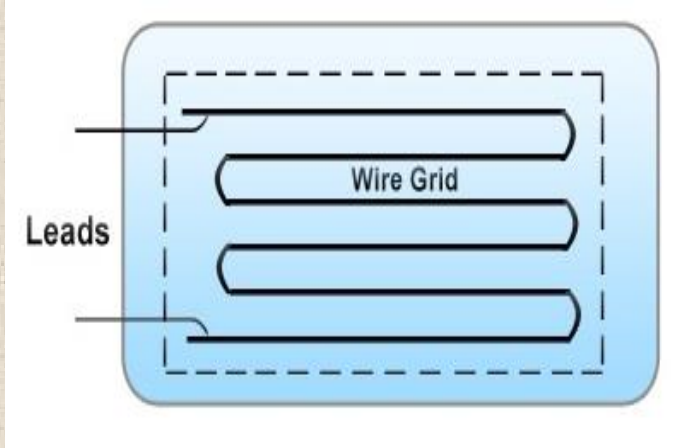
Various types of bonded strain gauges are:

1. Grid type:

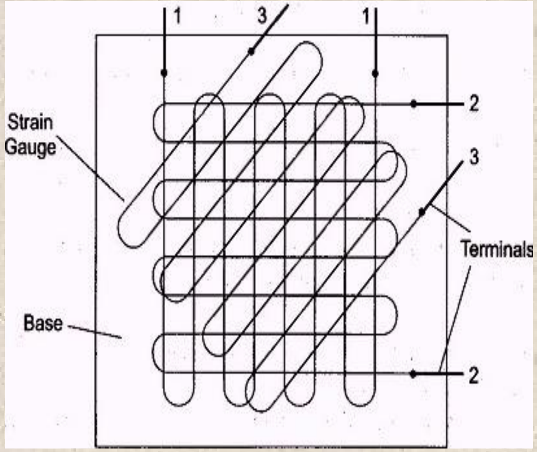
2. Rossette type: If the axis of the strain in a component is unknown, Strain Gauge Transducer Types may be used to determine the exact direction. The standard procedure is to place several gauges at a point on the member's surface, with known angles between them. The magnitude of strain in each individual gauge is measured, and used in the geometrical determination of the strain in the member. Shows a three-element strain gauge, called a **Rossette gauge**, in which the angle between any two longitudinal gauge axes is 45°.

3. Torque type:

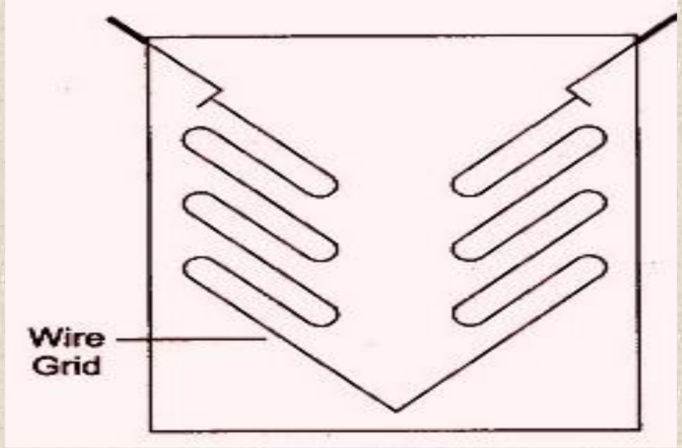
4. Helical type:



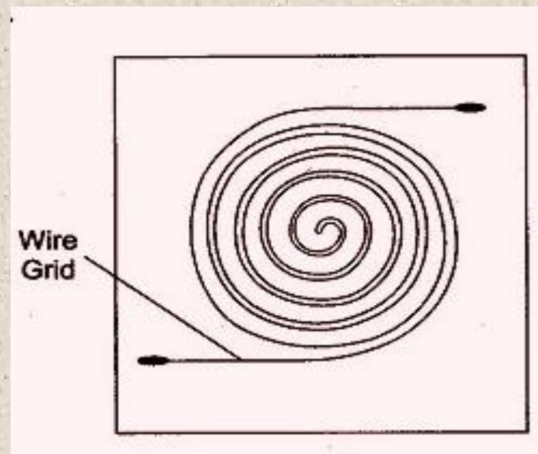
Grid type



Rossette type



Torque type

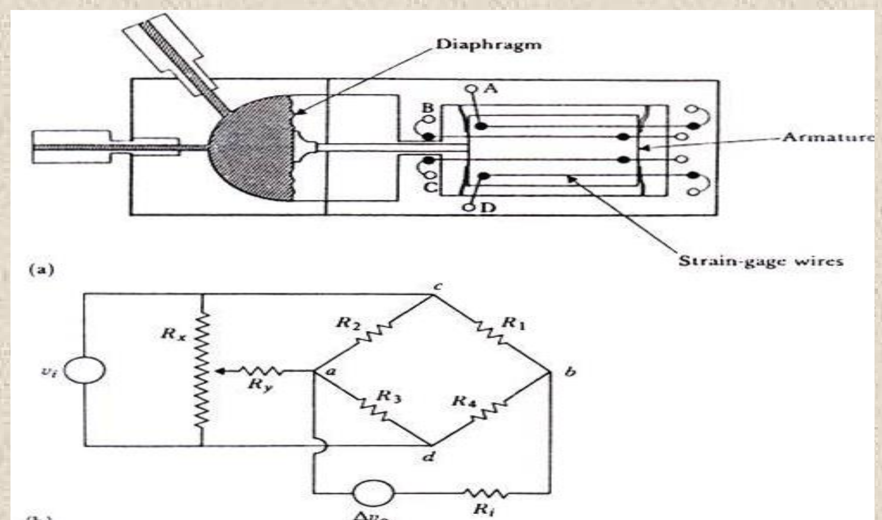


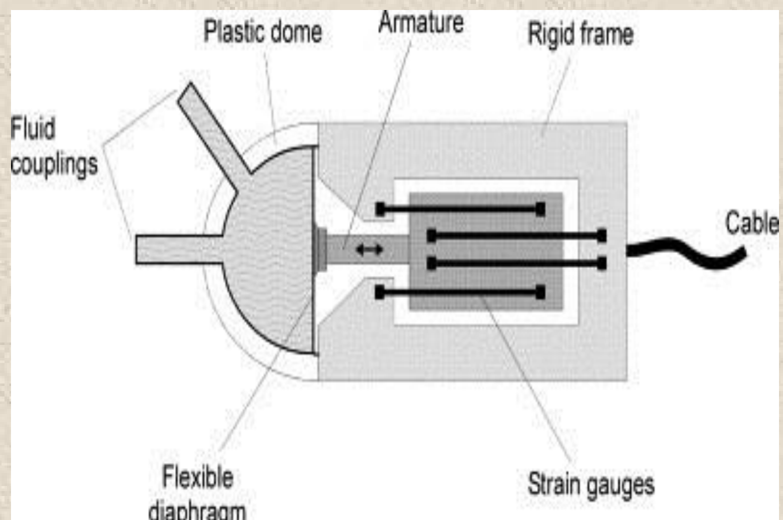
Helical type

Unbonded strain gauge: It is a type of gauge in which a wire is stretched in an insulating medium in between two points. The insulating medium can be air. The wire can be made of alloys such as copper-nickel, chrome nickel, nickel-iron having a diameter of about 0.003 mm. The gauge factor for this category of the strain gauge is about 2 to 4 and capable to withstand a force of 2MN.

These are almost exclusively used in transducer applications where preloaded resistance wires are connected in a Wheatstone bridge configuration.

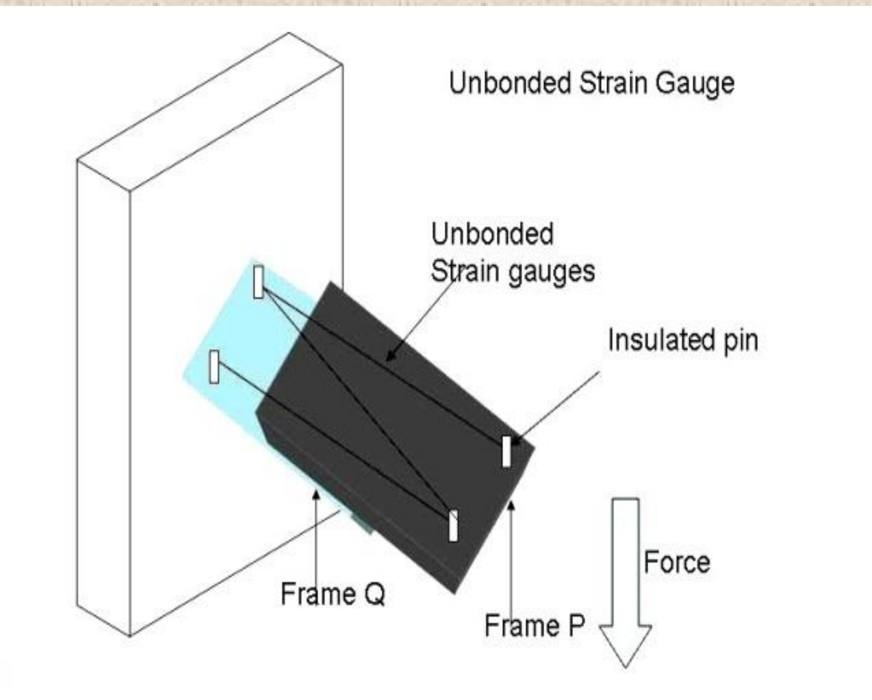
The arrangement of unbonded strain gauges consists of the following. Two frames P and Q carrying rigidly fixed insulated pins as shown in diagram. These two frames can move relative with respect to each other and they are held together by a spring loaded mechanism. A fine wire resistance strain gauge is stretched around the insulated pins. The strain gauge is connected to a wheat stone bridge.

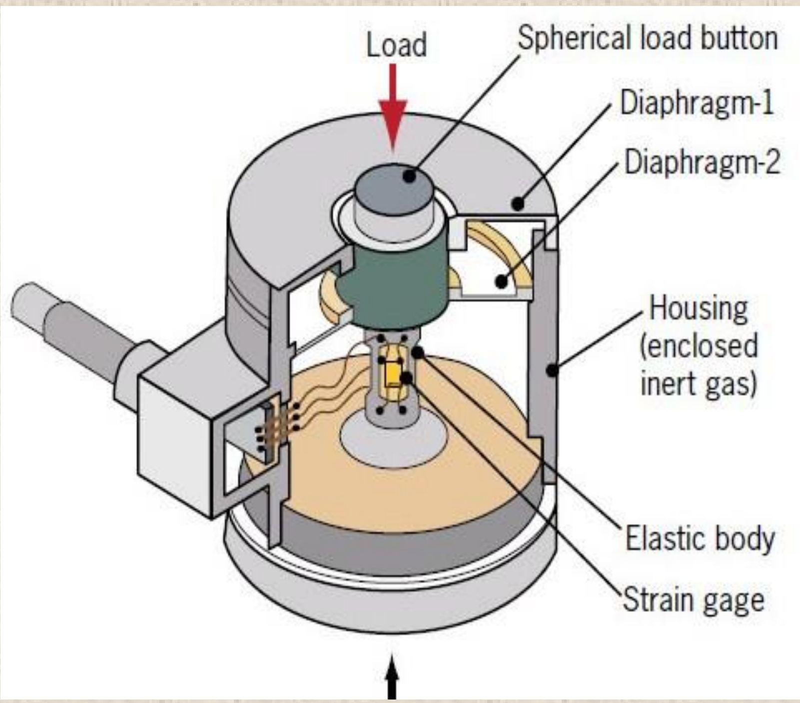




Operation of Unbonded strain gauges:

When a force is applied on the structure under study (frames P & Q), frames P moves relative to frame Q, and due to this strain gauge will change in length and cross section. That is, the strain gauge is strained. This strain changes the resistance of the strain gauge and this change in resistance of the strain gauge is measured using a wheat stone bridge. This change in resistance when calibrated becomes a measure of the applied force and change in dimensions of the structure under study.





Application of Unbonded strain gauge:

Unbonded strain gauge is used in places where the gauge is to be detached and used again and again.

unbonded strain gauges are used in force, pressure and acceleration measurement.

Advantages of Unbonded strain gauge:

The range of this gauge is +/- 0.15% strain.

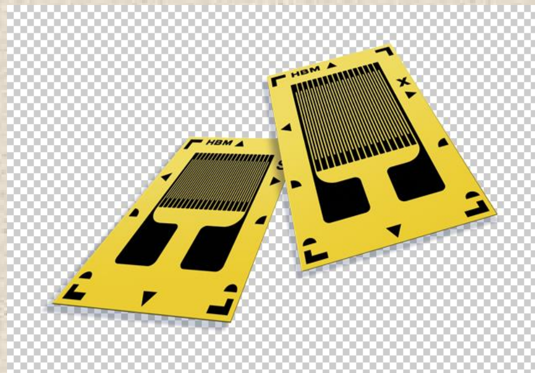
This gauge has a very high accuracy.

Limitation of unbonded strain gauges

It occupies more space.

Foil Strain Gauge: This is an extension of the resistance wire strain gauge. The strain is sensed with the help of a metal foil. The metals and alloys used for the foil and wire are nichrome, constantan (Ni + Cu), isoelastic (Ni + Cr + Mo), nickel and platinum.

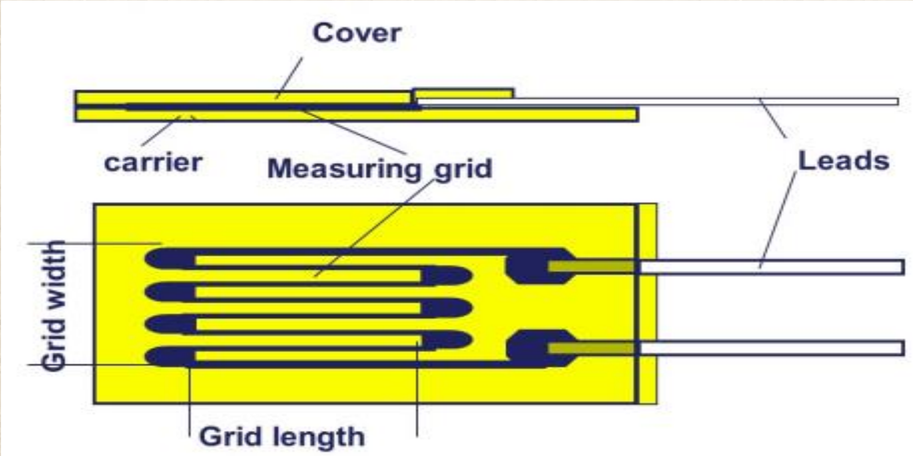
Foil gauges have a much greater dissipation capacity than wire wound gauges, on account of their larger surface area for the same volume. For this reason, they can be used for a higher operating temperature range. Also, the large surface area of foil gauges leads to better bonding. Foil type Strain Gauge Transducer Types have similar characteristics to wire strain gauges. Their gauge factors are typically the same.
The advantage of foil type Strain Gauge Transducer Types is that they can be fabricated on a large scale, and in any shape. The foil can also be etched on a carrier. Etched foil gauge construction consists of first bonding a layer of strain sensitive material to a thin sheet of paper or bakelite. The portion of the metal to be used as the wire element is covered with appropriate masking material, and an etching solution is applied to the unit. The solution removes that portion of the metal which is not masked, leaving the desired grid structure intact.



This method of construction enables etched foil strain gauges to be made thinner than comparable wire units, this characteristics, together with a greater degree of flexibility, allows the etched foil to be mounted in more remote and restricted places and on a wide range of curved surfaces.

The longitudinal sensitivity of the foil gauge is approximately 5% greater than that of similar wire elements. The transverse strain sensitivity of this gauge is smaller 1/3 to 1/2 of similar wire gauges. The hysteresis of the foil gauge is also 1/3 to 1/2 of a wire strain gauge.

The resistance film formed is typically 0.2 mm thick. The resistance value of commercially available foil gauges is between 50 and 1000 Ω the resistance films are vacuum coated with ceramic film and deposited on a plastic backing for insulation.



Semiconductor Strain Gauge: Semiconductor strain gauges are used when a very high gauge factor is required. They have a gauge factor 50 times as high as wire strain gauges. The resistance of the semiconductor changes with change in applied strain to have a high sensitivity, a high value of gauge factor is desirable. A high gauge factor means relatively higher change in resistance, which can be easily measured with a good degree of accuracy.

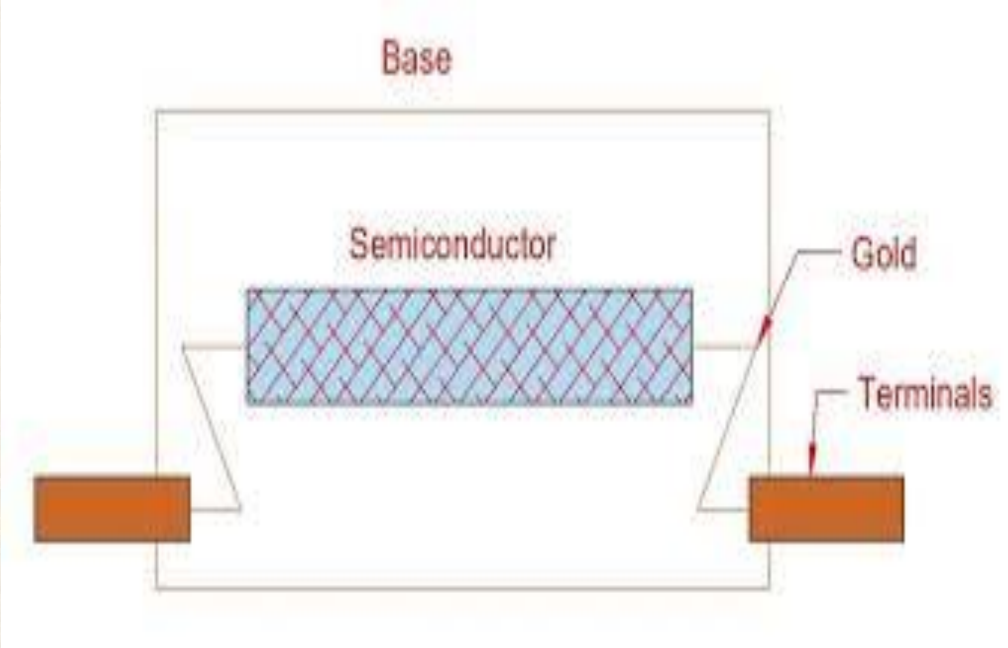
Semiconductor strain gauges depend for their action upon the piezo resistive effect, i.e. change in value of the resistance due to change in resistivity, unlike metallic gauges where change in resistance is mainly due to the change in dimension when strained. Semiconductor materials such as germanium and silicon are used as resistive materials.

A typical strain gauge consists of a strain material and leads that are placed in a protective box, Semiconductor wafer or filaments which have a thickness of 0.05 mm are used. They are bonded on suitable insulating substrates, such as Teflon.

Gold leads are generally used for making contacts. These strain gauges can be fabricated along with an IC Op Amp which can act as a pressure sensitive transducer. The large gauge factor is accompanied by a thermal rate of change of resistance approximately 50 times higher than that for resistive gauges. Hence, a semiconductor strain gauge is as stable as the metallic type, but has a much higher output.

Simple temperature compensation methods can be applied to semiconductor strain gauges, so that small values of strain, that is micro strains, can also be measured.

The gauge factor of this type of semiconductor strain gauge is 130 ± 10% for a unit of 350 Ω, 1″ long, 1/2″ wide and 0.005″ thick. The gauge factor is determined at room temperature at a tensile strain level of 1000 micro strain (1000 micro in/in. of length).



The maximum operating tensile strain is ± 3000 micro strain, with a power dissipation of 0.1 W. The semiconductor strain gauge also has low hysteresis and is susceptible to regular methods of temperature compensation. The semiconductor strain gauge has proved itself to be a stable and practical device for operation with conventional indicating and recording systems, to measure small strains from 0.1-500 micro strain.

Advantages of Semiconductor Strain Gauge:

1. Semiconductor strain gauges have a high gauge factor of about + 130. This allows measurement of very small strains, of the order of 0.01 micro

2. Hysteresis characteristics of semiconductor strain gauges are excellent, e. less than 0.05%.

3. Life in excess of 10 x 106 operations and a frequency response of 1012 Hz.

4. Semiconductor strain gauges can be very small in size, ranging in length from 0.7 to 7.0 mm.

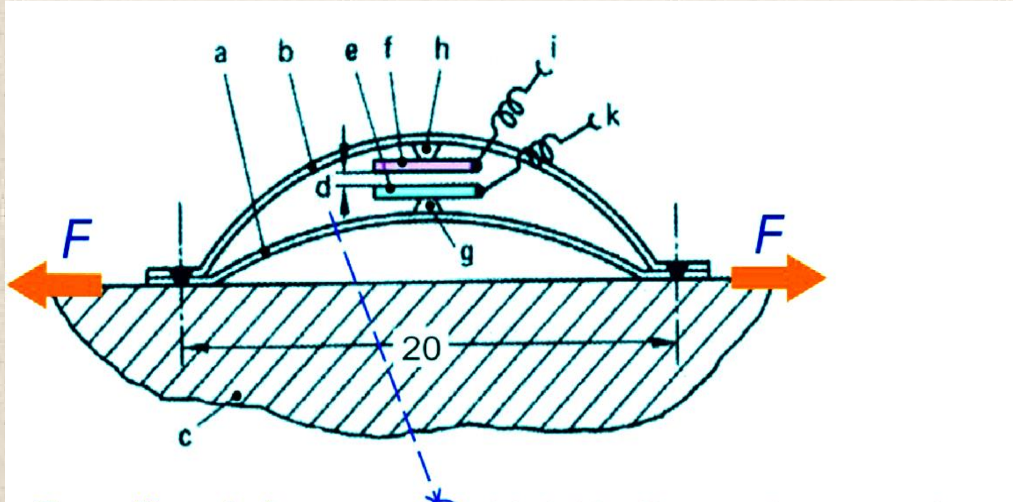
Disadvantages of Semiconductor Strain Gauge

1. They are very sensitive to changes in temperature.
2. Linearity of semiconductor strain gauges is poor.
3. They are more expensive.

Capacitive strain gauges: A capacitive strain gauge based on the principle of variation of capacitance with variation of distance between electrodes. The electrodes are flexible metal strips of about 0.1 mm thickness. The strain to be measured is applied to the top plate. These change the distance between the curved electrodes resulting in changes of capacitance. The strain capacitance relationship in general not linear but variations in dimensions and shape allow gauge characteristics to be chosen so as to match the range of capacitance to be measured with good degree of accuracy.

Specifications are:

1. Capacitance strain gauges have a range of about 0.5pF.
2. Its overall size is 5 mm x 17 mm x 1 mm
3. Temperature up to 300 ^{o}C
4. It uses a polyamide film of insulating material.



Capacitive strain gauge: d - Variable distance between plates

In the figure:

a-b = are the elastic strip
c = measurement base
e-f = electrodes
g-h = ceramic support
i-k = flexible cable

GAUGE FACTOR

The gauge factor is defined as the unit change in resistance per unit change in length. It is denoted as G or S. It is also called sensitivity of the strain gauge.

$$\text{Gauge factor } G_f = \frac{\Delta R/R}{\Delta L/L}$$

Where ΔR = Corresponding change in resistance R

ΔL = Change in length per unit length.

The resistance of the wire of strain gauge R is given by:

$$R = \frac{\rho . L}{A}$$

Where ρ = resistivity of the material of wire

L = length of the wire

A= cross sectional Area of the wire, Kd^2 , K is constant and D is the diameter.

As earlier stated when the wire is strained its length increases and the lateral dimension is reduced as a function of poisson's ratio (μ); consequently there is an increase in resistance

$$R = \frac{\rho.L}{K\,D^2}$$

Differentiating it, we get

$$dR = \frac{K\,D^2\,(\rho.dL + L.d\rho) - \rho L(2KD.dD)}{(K\,D^2)^2}$$

$$= \frac{1}{K\,D^2}\left[(\rho.\,dL + L.\,d\rho) - 2\,\rho L\left(\frac{dD}{D}\right)\right.$$

$$\frac{dR}{R} = \frac{\frac{1}{K\,D^2}\left[(\rho.dL + L.d\rho) - 2\,\rho L\left(\frac{dD}{D}\right)\right.}{\frac{\rho.L}{K\,D^2}}$$

$$= \frac{dL}{L} + \frac{d\rho}{\rho} + 2\frac{dD}{D}$$

Now passion ration, $\mu = \dfrac{lateral\ strain(-\frac{dD}{D})}{longitudinal\ strain(\frac{dL}{L})}$

$$\frac{dD}{D} = -\,\mu \times dL / L$$

For small variation the above relationship can be written as:

$$\frac{dR}{R} = \frac{\Delta L}{L} + \frac{\Delta \rho}{\rho} + 2\mu \frac{dD}{D}$$

$$\text{Gauge factor } G_f = \frac{\Delta R/R}{\Delta L/L}$$

$$\frac{dR}{R} = G_f \frac{\Delta L}{L} = G_f \times e$$

Where $e = \frac{\Delta L}{L}$

The gauge factor can be written as

$$\boxed{\mathbf{G_f = 1 + 2\mu + \frac{\Delta\rho/\rho}{e}}}$$

Thank you